Appendix E

Influence of Net Freshwater Supply on Salinity in Florida Bay (Nuttle 2000)

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Influence of net freshwater supply on salinity in Florida Bay

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Abstract. An annual water budget for Florida Bay, the large, seasonally hypersaline estuary in the Everglades National Park, was constructed using physically based models and long-term (31 years) data on salinity, hydrology, and climate. Effects of seasonal and interannual variations of the net freshwater supply (runoff plus rainfall minus evaporation) on salinity variation within the bay were also examined. Particular attention was paid to the effects of runoff, which are the focus of ambitious plans to restore and conserve the Florida Bay ecosystem. From 1965 to 1995 the annual runoff from the Everglades into the bay was less than one tenth of the annual direct rainfall onto the bay, while estimated annual evaporation slightly exceeded annual rainfall. The average net freshwater supply to the bay over a year was thus approximately zero, and interannual variations in salinity appeared to be affected primarily by interannual fluctuations in rainfall. At the annual scale, runoff apparently had little effect on the bay as a whole during this period. On a seasonal basis, variations in rainfall, evaporation, and runoff were not in phase, and the net freshwater supply to the bay varied between positive and negative values, contributing to a strong seasonal pattern in salinity, especially in regions of the bay relatively isolated from exchanges with the Gulf of Mexico and Atlantic Ocean. Changes in runoff could have a greater effect on salinity in the bay if the seasonal patterns of rainfall and evaporation and the timing of the runoff are considered. One model was also used to simulate spatial and temporal patterns of salinity responses expected to result from changes in net freshwater supply. Simulations in which runoff was increased by a factor of 2 (but with no change in spatial pattern) indicated that increased runoff will lower salinity values in eastern Florida Bay, increase the variability of salinity in the South Region, but have little effect on salinity in the Central and West Regions.

1. Introduction

Florida Bay, a broad (2000 km^2), shallow (approximately 1 m) estuarine lagoon nestled between the south Florida mainland and the Florida Keys (Figure 1), occupies a large portion of Everglades National Park and is contiguous with the Florida Keys National Marine Sanctuary. It is bounded by the mangrove wetlands of the mainland, the open marine systems of the Gulf of Mexico, and the islands that compose the Florida Keys. Bay waters support a valuable recreational fishery within the bay itself [*Tilmant*, 1989] and a commercial shrimp fishery in the Gulf of Mexico [*Costello and Allen*, 1966]. Beginning in 1987, sudden and extensive die-off in the sea grass beds that cover 95% of the bottom signaled a rapid, general decline in the ecological health of the bay [*Robblee et al.*, 1991; *Fourqurean et al.*, 1993; *Phlips et al.*, 1995]. Increased turbidity followed die-off in the grass beds [*Boyer et al.*, 1999], and recurrent blooms of cyanobacteria in the winters of 1991–1992 and 1992–1993 decimated the sponge population [*Butler et al.*, 1995]. The resulting changes in water quality and the long-term structural changes in the bay's ecosystems have also affected the health of adjacent coastal systems, such as the coral reefs of the Florida Keys.

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Ecological decline in Florida Bay is widely considered to be the result of long-term regional water management in south Florida. Although there is general agreement about the nature and extent of the impacts of water management in the extensive wetlands of the Everglades, which lie immediately upstream of Florida Bay, the chain of cause and effect linking water management to sea grass die-off and plankton blooms in the bay has not yet been fully established. Because of management practices, discharge of freshwater directly into the Atlantic Ocean and farther north into the Gulf of Mexico has increased up to a factor of 10, while the discharge of freshwater into Florida Bay and along the southwest coast of Florida has decreased by an unknown but important amount [*Light and Dineen*, 1994]. Because we do not know the sensitivity of the Florida Bay ecosystem, primarily the extensive sea grass communities, to variations in freshwater runoff, we cannot tell what benefits restoring the historical runoff would have. Even without this knowledge, plans for water management and ecosystem restoration in south Florida [*U.S. Army Corps of Engineers*, 1998] are progressing, based, at least in part, on the assump-

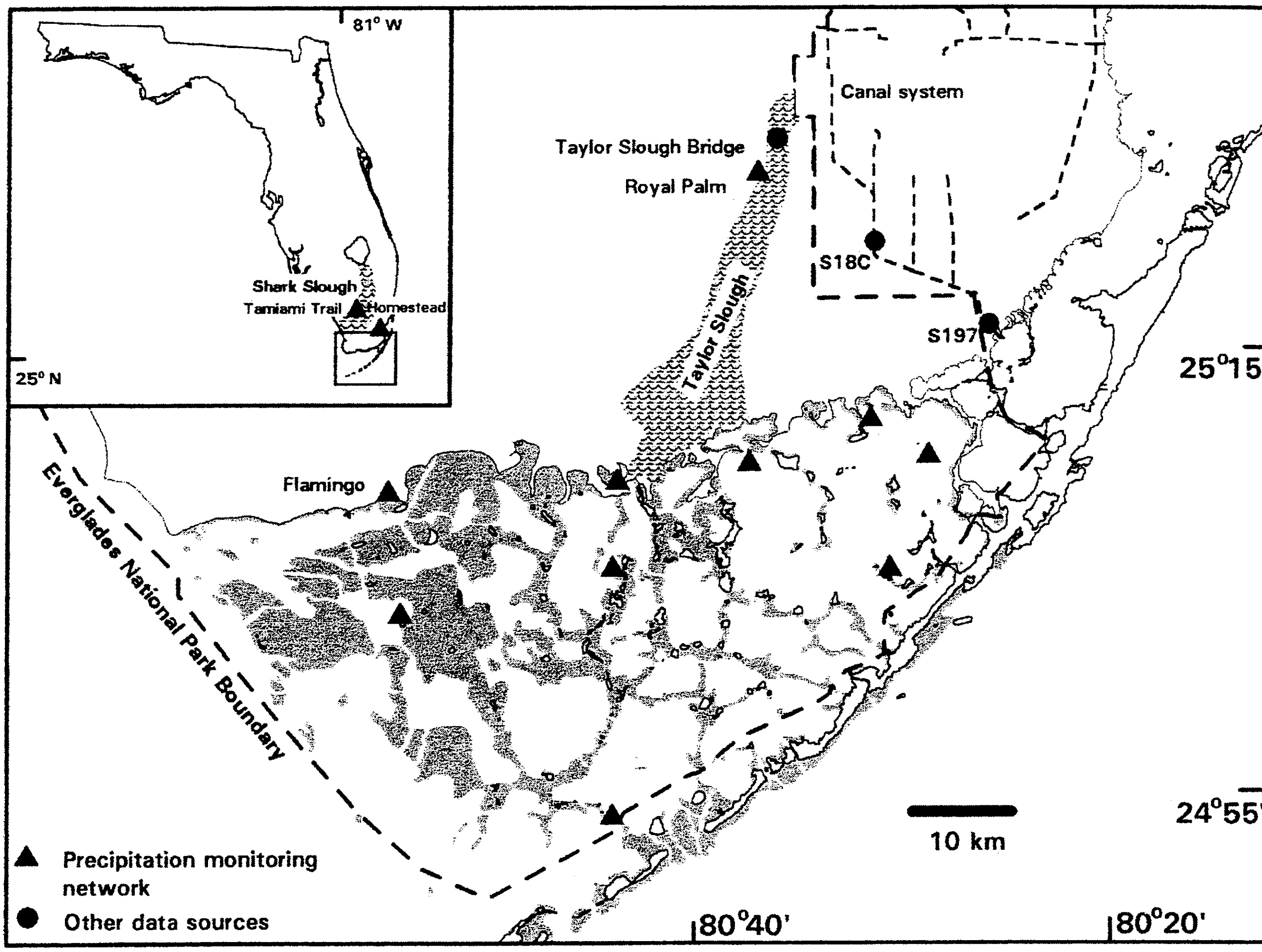

Figure 1. Broad, shallow (<30 cm) seagrass-covered mudbanks (shaded area) restrict water exchange between Florida Bay and the coastal ocean. Freshwater enters the bay as runoff through Taylor Slough and as diffuse flow from the wetlands to the east. Regional discharge through Shark Slough (inset) also influences salinity in the Gulf of Mexico on the western boundary of the bay. Locations are shown for sources of data on rainfall (points in the bay), pan evaporation (Flamingo), and runoff (Taylor Sough Bridge and the control structures S18C and S197 on the C111 canal).

tion that the ecological health of Florida Bay will be restored by increasing the freshwater runoff to the bay to as near to historic levels as possible.

Salinity is an intermediate link in the chain of cause and effect that connects water-management activities to the structure and functions of the bay's ecosystem. In Florida Bay, salinity varies markedly in time and space (Figure 2). Hypersaline conditions (>40) (salinity values given in practical salinity units) in one part of the bay frequently coexist with more estuarine conditions (<30) in another. At some interior locations, salinity regularly fluctuates between hypersaline and nearly freshwater conditions [*Frankovich and Fourqurean*, 1997]. Only within the confines of a few, semienclosed basins along the north shore of the bay do salinity fluctuations closely follow changes in canal discharge. The degree to which water management and, consequently, runoff from south Florida influence salinity fluctuations in Florida Bay cannot be ascertained without a detailed analysis. Therefore we have used salinity, hydrology, and climate data from 1965 through 1995 to investigate how the annual water balance and the variations in freshwater fluxes have influenced the salinity in Florida Bay.

2. Background

2.1. Factors Affecting Estuarine Salinity

Variation in estuarine salinity can be attributed to the intensity of the two-way exchange between the estuary and the coastal ocean, the net supply of freshwater that flows through the estuary to the coastal ocean, and the salinity of the coastal ocean at the estuary's mouth. The two-way exchange between estuary and ocean is driven by several physical processes, including density differences, astronomical tides, and wind. The net freshwater supply is the sum of runoff and direct rainfall minus any evaporation from the estuary. The patterns of salinity in estuaries result from a dynamic steady state in which the advective flux of salt into or out of the estuary, which is driven by the net freshwater supply, is balanced by a dispersive flux from the two-way water exchange created by tides and other hydrodynamic mixing processes.

In a classical estuary a positive net freshwater supply, usually from heavy runoff delivered by river discharge, dilutes the salinity in the estuary to below that of ocean water. Salinity ranges from zero at the head of the estuary to the salinity of the coastal ocean near the mouth.

Other estuaries may experience hypersaline conditions. Many coastal bays and lagoons, like Shark Bay, Western Australia [*Smith and Atkinson*, 1983]; Laguna Madre, Texas, United States of America [*Smith*, 1988]; and Lagoa de Araruama, Brazil [*Kjerfve et al.*, 1996], have higher average salinities near their mouths than the coastal ocean for most or all of the year. Because these inverse estuaries have a negative freshwater supply caused by evaporation rates higher than both rainfall and runoff rates, salt concentrates to hypersaline conditions. Salinities in these inverse estuaries can range from zero near freshwater discharge to a greater-than-coastal salinity in the main body of the estuary.

Seasonally hypersaline estuaries form a third class of estuary characterized by their episodic hypersalinity [*Largier et al.*, 1997]. These estuaries experience limited exchange with the coastal ocean, and net freshwater supply fluctuates on the positive and negative side of zero in response to climatic variations. Estuaries in this class are found in both temperate, Mediterranean climates (e.g., Tomales, Mission, and San Diego Bays, California, United States of America [*Largier et al.*, 1997]) and tropical, monsoonal areas (e.g., northern Australia [*Wolanski*, 1986], Kenya [*Kitheka*, 1998], and Sri Lanka [*Arulananthan et al.*, 1995]). Since the net annual freshwater balance of seasonally hypersaline estuaries is close to zero, small perturbations in the freshwater supply may lead to large changes in the salinity of the estuary. Diversions of freshwater runoff for urban or agricultural use, as in the Colorado River Estuary, Mexico, can drastically change the salinity regime. Small climactic variations can also have large impacts on salinity: For example, a multidecadal trend of decreasing rainfall has changed the Casamance River Estuary in Senegal from a seasonally hypersaline estuary to a permanently inverse estuary [*Debenay et al.*, 1994]. In Laguna Madre, Texas, prolonged and intense hypersaline conditions associated with droughts may trigger the "brown tide" phenomenon by changing the structure of the plankton community [*Rhudy et al.*, 1999].

Florida Bay is a seasonally hypersaline estuary (Figure 2a). In the bay a network of broad, shallow mud banks and the lack of density stratification limit the magnitude of tidally driven and baroclinic exchange flows. The influence of the south Florida climate is evident in runoff, rainfall, wind-driven tides, and the salinity of the coastal ocean. Wet and dry periods fluctuate seasonally and from year to year. Tides and currents in the bay are particularly influenced by the sustained winds associated with the passage of fronts characteristic of the subtropical winter weather [*Wang et al.*, 1994]. Patterns of local runoff from the Everglades directly affect salinity in the bay (Figure 2b). Variations in runoff from all of south Florida, including Lake Okeechobee, influence the salinity of the Gulf of Mexico along its border with Florida Bay thereby indirectly linking regional patterns of runoff to salinity variations in the bay.

2.2. Regional Patterns in Florida Bay

Florida Bay lacks the clearly defined upstream/downstream axis that, in most estuaries, organizes spatial variations in salinity. However, several analyses of water-quality parameters, for example, salinity, nutrient, chlorophyll, etc., have shown a consistent pattern. For example, *Boyer et al.* [1997] identified three zones of similar water quality in Florida Bay: a core region, a western region, and an eastern region. Other authors have suggested dividing the bay into similar zones based on

a

b

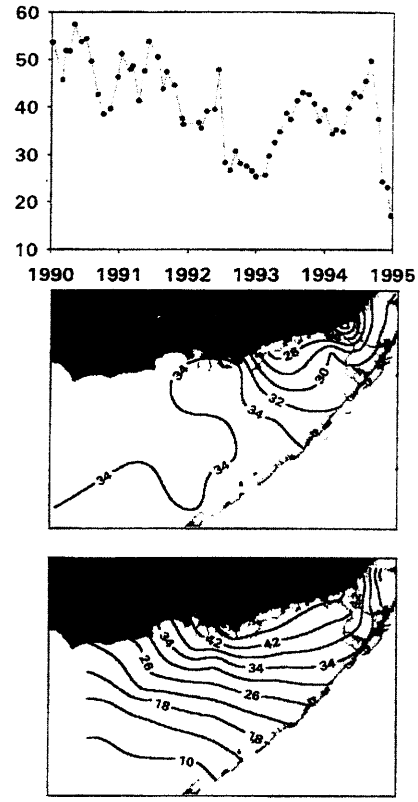

Figure 2. Salinity varies widely in time and space in Florida Bay. (top) Temporal patterns in the Central Region reflect the influence of sources of variation operating on seasonal and interannual timescales. (middle) Spatial patterns in mean salinity from February to March 1994 and (bottom) range of salinity variation from 1990 to 1994 over the whole bay reveal the influence of exchange with ocean waters and the localized effect of runoff into the bay.

bank morphology and dynamics [*Wanless and Tagett*, 1989], benthic mollusk communities [*Turney and Perkins*, 1972], salinity and nitrogen [*Fourqurean et al.*, 1993], and benthic plant communities [*Zieman et al.*, 1989]. These schemes all suggest that the primary axis of differentiation runs from northeast to southwest, and most schemes include a separate, distinct region (of varying size) in the upper central part of the bay adjacent to the Everglades.

On the basis of the work summarized above, for this study we divided the bay into four regions (Figure 3) that differ in their proximity to the Gulf of Mexico, areas of water flow through the Florida Keys, and sources of freshwater runoff from the mainland. In the Central Region, broad, shallow banks (Figure 1) restrict exchange with the Gulf and the Atlantic, and there is little freshwater runoff. Residence times are high and hypersaline conditions are frequent and persistent (Figure 2a). The East Region resembles the Central Region with its limited oceanic exchange and long residence times; however, it receives most of the bay's freshwater runoff primarily from the C111 canal and Taylor Slough (Figure 1). Salinity in the East Region varies widely between nearly fresh and hypersaline conditions (Figure 2b). In the South and West Regions, salinity variations are less extreme (Figure 2b). Greater exchange with the Gulf of Mexico and the Atlantic

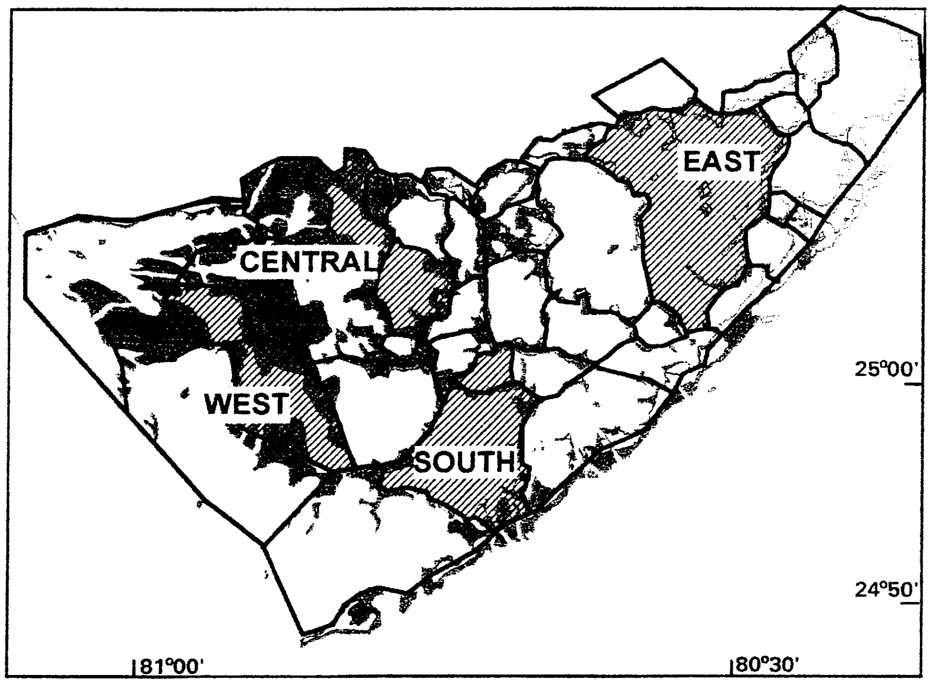

Figure 3. Subtidal banks and islands divide Florida Bay into 44 basins used to categorize the location of salinity observations. On a larger scale, studies of water quality, sediment type, faunal communities, and benthic plant communities generally divide the bay into four regions of similar character. This study uses data from an aggregation of basins within each of these four regions (hatched area) to characterize the spatial and temporal variations in Florida Bay.

Ocean and a lack of direct runoff result in salinities nearer to that of the coastal waters.

3. Methods

The main objectives of this study were (1) to establish the annual and seasonal water balances and net freshwater supplies for Florida Bay and (2) to evaluate the degree to which the amounts of and variations in rainfall and runoff contribute to the observed salinity variations in Florida Bay. The influence on salinity of any of the components of the net freshwater supply could not be demonstrated simply by searching for correlations with salinity. Most factors controlling estuarine salinity share climate as a common source of variation, and each can be expected to exhibit similar patterns of variation. The only way to understand the influence of a particular component of the net freshwater supply on salinity in Florida Bay was to isolate that component and quantify directly its effect on salinity.

This approach required spatially and temporally extensive measurements of freshwater fluxes and salinity in the bay, salinity models that incorporated different temporal and spatial scales, and a framework for interpreting the simulated and observed salinity variations. We assembled rainfall, runoff, and evaporation data and a database of published and unpublished salinity measurements in Florida Bay (see the appendix) that spans the 31 years from 1965 through 1995. We used the annual and monthly means of these data to establish the yearly and seasonal water balances for Florida Bay. We then used the data with physically based, mass balance salinity models in comparative analyses to examine the effects of spatial and temporal variations in net freshwater supply on the observed salinity variations.

3.1. Framework for the Comparative Analyses

In general, physically based models treat salinity, S, as a function of coastal ocean salinity, S_{ocn}, exchange fluxes with the coastal ocean, Q_T, and the fluxes of freshwater (rainfall, Q_P, runoff, Q_R, and evaporation, Q_E), all of which vary in time and space:

$$S|_{j,k}^{i} = f(S_{\mathrm{ocn}}|_{j,k}^{i}, Q_T|_{j,k}^{i}, Q_E|_{j,k}^{i}, Q_P|_{j,k}^{i}, Q_R|_{j,k}^{i}) + R|_{j,k}^{i}, \quad (1)$$

where the superscript and subscripts identify location (i), year (j), and month (k). The residual errors, R, are the differences between measured and simulated salinity and represent noise in the data and salinity variations not explained by the processes or assumptions inherent in the model formulations. We employed models that differed in their spatial and temporal resolution and compared the successes of the models in reproducing observed salinity variations in order to draw inferences about the importance for salinity variations of (1) interannual and seasonal variations in net freshwater supply and (2) location within the bay.

We used a measure of model efficiency, eff, to assess how successfully each model reproduced the patterns of variation in observed salinity data:

$$\mathrm{eff} = 100\left[1 - \frac{\sum_i \sum_j \sum_k (R|_{j,k}^{i})^2}{n \operatorname{Var}(S|_{j,k}^{i})}\right], \quad (2)$$

where R are the residual errors, Var (S) is the total variance of the salinity measurements, and n is the number of observations. A model's efficiency score (unitless) can be broadly interpreted as the proportion of the variance in the data explained by the model. In this sense, model efficiency is similar to the coefficient of determination r^2. In contrast to r^2 the efficiency score can take on negative values if, for example, the model produces a biased estimate of the data or if fluctuations in the model are out of phase with fluctuations in the data. If the efficiency score was zero, then the model explained the variation in the data no better than did the mean of the data. If the efficiency score was 100%, then the residuals were zero, and the model explained all of the variance in the data.

Any measure of model success is most useful if comparatively applied. That is, by examining the increase (or decrease) in explanatory power between a null model and an alternative, the power of the processes included in the alternative model to explain variance in the data can be assessed. The null model implicitly included in eff was the mean of the observed salinity across all observations and all regions in Florida Bay (i.e., a model with no temporal or spatial resolution). We developed three alternative salinity models that contained increasing spatial and temporal complexities. By comparing the efficiencies of the alternative models, we were able to estimate the relative contributions of two temporal components (interannual and seasonal variations in freshwater fluxes) and one spatial component (location of the salinity measurements) to the overall variation of salinity in Florida Bay.

The first type of model, a static location model, only accounted for the effects on salinity of position within the bay. This model was simply defined as the average of the observed salinity data, S_{av}, for all months and years in each region of the bay:

$$S|_{j,k}^{i} = S_{\mathrm{av}}|^{i} + R|_{j,k}^{i}. \tag{3}$$

The location model was applied to each of the four regions in Figure 3. The model did not contain a temporal component and could not explain any of the interannual or seasonal variations of salinity within any of the regions. The notation denotes that the model simulated a salinity value S for each region (i), every year (j), and every month (k), but the predicted salinity for all months and years in a region was the same value. Because the model has no temporal component (only the spatial means are used), the residuals were expected to contain all of the temporal variance in the data, and the efficiency was expected to be low.

The second type of model, a steady state, spatially aggregated "box" model, quantified the effects of location as well as the effects of long-term, interannual variations in rainfall and runoff on salinity within the bay:

$$S|_{j,k}^{i} = f(S_{\mathrm{ocn}}, Q_T|^{i}, Q_E|^{i}, Q_P|_{j}, Q_R|_{j}) + R|_{j,k}^{i}. \tag{4}$$

The box model was implemented using annual time steps and annual values of freshwater and exchange fluxes. Rainfall and runoff were uniformly distributed over the bay (no spatial component) and varied from year to year. Spatially explicit but temporally constant estimates of evaporation and dispersive exchange with the coastal ocean were derived for the model during calibration. This model was applied to all four regions in the bay (Figure 3). The residuals were expected to contain all of the seasonal variance, and the efficiency was expected to increase over that of the location model.

The third type of model, a dynamic, spatially explicit model, simulated the effects on salinity of location and both interannual and seasonal variations in freshwater and exchange fluxes:

$$S|_{j,k}^{i} = f(S_{\mathrm{ocn}}, Q_T|_{j,k}^{i}, Q_E|_{k}, Q_P|_{j,k}, Q_R|_{j,k}^{i}) + R|_{j,k}^{i}. \tag{5}$$

The dynamic model was based on the basin and bank geomorphology of Florida Bay and was driven by monthly values of rainfall, runoff, and evaporation. Rainfall and evaporation were applied uniformly across the bay, but runoff was added at appropriate locations on the boundaries of the bay. Hourly tides generated advective exchanges among 44 basins within the bay. We expected this model, with the greatest spatial and temporal complexity, to have the highest efficiency and explanatory power.

3.2. Salinity Data

We drew our salinity observations for this study from an historical salinity database for Florida Bay and the west coast of south Florida consisting of over 34,000 individual observations dating from 1947 (see the appendix). This database was assembled from the results of many field studies and from systematic, water-quality monitoring programs initiated in response to the ecological crises of the late 1980s and early 1990s. Data from within Florida Bay are categorized according to their location in a grid of 44 numbered basins. Boundaries of the basins follow the geometry of the system of anastomosing banks that physically subdivide the bay (Figure 3). This database provides excellent spatial and temporal coverage beginning with 1989 when mounting concern about conditions in the bay resulted in the establishment of regular water-quality monitoring surveys. However, the data from before 1989 are discontinuous and uneven with the highest number of observations clustered in the East Region of the bay. Because the data available from before 1965 are extremely spotty, they were not used in this study.

We aggregated the salinity data by subsampling and processing data from the historical database to assure an unbiased sampling of the interannual and seasonal salinity variations and to provide a balanced representation of the regional variations in the bay. First, the data were aggregated in time by computing the individual monthly average salinity in each basin for each month of record. Second, the data in each basin were screened to assure they consistently represented seasonal variations by excluding calendar years with data reported in fewer than 11 months. Third, in all but the East Region, data from two adjacent basins were combined to provide the most continuous salinity record possible (maximum number of years) over the 31 years (Figure 3). The resulting set of monthly averaged salinity data characterized the interannual and seasonal variations in salinity in each region of the bay for 1965 through 1995 (Figures 4 and 5). The nine years from 1987 to 1995 contain 34 station years (54%) of the data. We used this data subset, the evaluation period subset, for our detailed comparisons of the model results because it provided the most complete temporal and spatial coverage of the bay. Our evaluation of the influence of the net freshwater supply on salinity was primarily based on our analysis of these data. We used the additional data in the complete 31-year record to evaluate the predictive ability of the models. The distribution of salinity data in the 9-year evaluation period was similar to that of the complete 31-year record (Table 1).

3.3. Freshwater Flux Data

3.3.1. Runoff. Freshwater runoff into Florida Bay was estimated as the sum of monthly volume discharges in Taylor Slough and the C111 canal (Figure 6a). Data for Taylor Slough are available for the entire period from 1965 through 1995; data for the C111 canal are only available beginning in 1970.

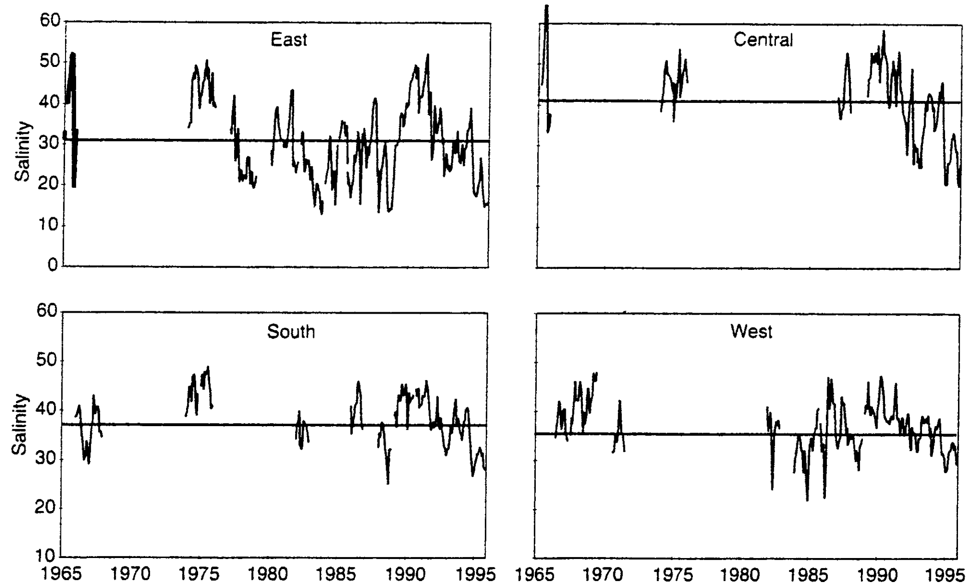

Figure 4. Monthly salinity values for 1965 to 1995 for each of four aggregated basins in Florida Bay show the combined influence of a strong seasonal cycle superimposed on interannual variation. The straight lines indicate the average salinity in each region for the period.

Discharge in Taylor Slough is measured as it crosses the main road through Everglades National Park (Figure 1). The flow down Taylor Slough discharges into a complex of ponds north of the bay and is distributed from there into the bay through several, smaller channels. Discharge in the C111 canal is measured at the S18C and the S197 control structures (Figure 1). The C111 canal conveys water from a regional network of drainage canals. Most water that leaves the C111 canal discharges into the mangrove wetlands between the S18C and the S197 structures. This freshwater then flows south into the East Region of the bay. During infrequent periods of extremely high flow, water is allowed to pass through the S197 structure and discharge directly into the extreme eastern end of Florida Bay. These runoff data do not account for the net gain (or loss) of freshwater from precipitation and evaporation over the area between the flow-monitoring points and the coast. The contribution of (ungauged) groundwater flow to the coast is also not accounted for in these data. Evidence from natural groundwater tracers suggests that submarine groundwater discharge into Florida Bay contributes only slightly to the net freshwater supply [*Corbett et al.*, 1999].

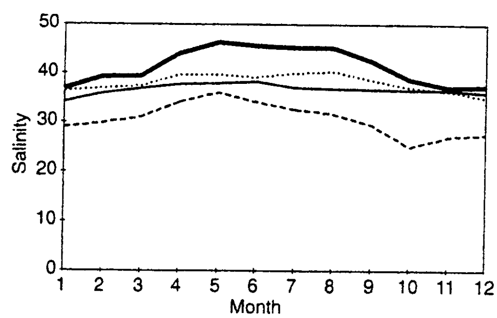

Figure 5. Regional salinity averaged by month over all 31 years illustrates similarities and differences in the seasonal patterns of variation. In all regions, salinity increases during the dry season and decreases during the wet season. The amplitude of seasonal variation is greater in the Central and East Regions (bold and dashed lines), which are isolated from active exchange with the coastal ocean, which moderates the seasonal variation in the South and West Regions (dotted and fine lines).

3.3.2. Rainfall. The available long-term rainfall records for land-based sites in south Florida do not provide reliable estimates of rain falling directly onto the bay. Convective storms form primarily along the coast early in the wet season but do not form over the open water of the bay until late in the wet season [*Schomer and Drew*, 1982]. This produces higher rainfall measurements at mainland stations just inland from the Florida Bay coast than actually occur in the bay. Therefore, to construct a long-term precipitation record for the bay, we had to correct for this bias in the land-based records. We did this by correlating land-based records with recently available rainfall measurements from stations within the bay and using this correlation to reconstruct rainfall for periods when no rainfall data for the bay were available.

Rainfall is currently being measured at several marine-monitoring network stations maintained in Florida Bay (D.

Table 1. Summary of the Monthly Average Salinity Observations in Each Region of Florida Bay

	1987–1995		1965–1995	
Basin	Mean	SD	Mean	SD
East	30.8	9.8	30.6	9.6
South	37.0	5.2	38.1	5.2
Central	39.6	9.4	41.4	9.2
West	36.4	4.2	36.7	5.0
All basins	35.8	8.2	35.8	8.6

SD is standard deviation.

Smith, Annual Data Reports: 1993–1996, Everglades National Park, Homestead, Florida). We used the monthly totals for 1993 through 1996 from eight of these stations (Figure 1) to estimate monthly bay-wide average rainfall for 1993 through 1996. We chose these stations because they reported at least 12 months of data within this period. We used linear regression to identify relationships between the monthly totals at each of the eight marine monitoring stations and monthly rainfall amounts from long-term records (National Weather Service, National Oceanic and Atmospheric Administration (NOAA), data available from the National Climatic Data Center, Asheville, North Carolina) for Flamingo, Royal Palm, Tamiami Trail, and Homestead (Figure 1). These relations, which have r^2 generally greater than 0.5, provided the means of extrapolating the recent record of rainfall in the bay back in time over the period 1965 through 1995. We calculated a bay-wide average rainfall from the extrapolated records, using area weights based on Thiessen polygons, to estimate annual and monthly, bay-wide average rainfall (Figure 6b).

3.3.3. Evaporation. Evaporation has not been directly measured in Florida Bay, and as yet little effort has been made to evaluate the long-term evaporation rate or its seasonal or regional variations. Several years (1965 through 1970) of pan evaporation observations are available from a National Weather Service cooperative observing station (data available from the National Climatic Data Center) at Flamingo on the southwest Florida mainland (Figure 1). The annual average of these data (approximately 210 cm yr^{-1}) appeared to be too high to be accepted as direct estimates of evaporation in Florida Bay. By comparison, *Morton* [1986] estimates annual evaporation from Lake Okeechobee is 162 cm based on a calculation of its water budget. Recently, *Pratt and Smith* [1999] estimated an annual evaporation rate of about 73 cm by using a Dalton law formula and data collected at three sites in the bay. However, since some data needed to apply this formula were obtained from a fourth station outside of the bay, it is not known what magnitude of error might have been introduced into their estimate. Because of the lack of reliable evaporation estimates we derived our own estimate of the long-term, bay-wide, annual average evaporation rate, E_B, from our calibration of the steady state box model using the annual averages of the observed salinity data (see section 3.4.1). Then, we estimated monthly values of evaporation, Q_E, by multiplying the long-term, annual rate by monthly weights, w_k, derived from the seasonal pattern in the pan data from Flamingo:

$$Q_E = E_B w_k, \tag{6}$$

where

$$\sum_{k=1}^{12} w_k = 1.$$

3.4. Salinity Models

3.4.1. Steady state box model. The steady state box model served two purposes. It allowed us (1) to estimate the unknown evaporation flux and (2) to investigate what effect year-to-year variations in net freshwater supply has had on bay salinity. We formulated the box model following the approach of *Miller and McPherson* [1991] at Charlotte Harbor. In this approach the net effects of residual circulation and hydrodynamic mixing were accounted for by a (unknown) net exchange flux, Q_T, for each region of the bay that represented the cumulative influx of seawater flowing into that region. These exchange fluxes, expressed in cm yr^{-1}, were assumed to be constant with respect to season and year. Each region also received a net supply of freshwater, Q_F, as a result of runoff, direct rainfall, and evaporation. Invoking mass conservation for both water and salt led to an expression for the steady state salinity in each region. On an annual average basis a flux of water, Q_T, with salinity, S_{ocn}, entered each basin from the ocean and a flux of water, Q_T plus Q_F, returned to the ocean with the salinity in the basin. Equating the inflow and outflow, advected fluxes of salt led to an expression for the annual average, steady state salinity in the efflux (S_{ann}, i.e., an estimate of the annual average salinity in a given region of the bay):

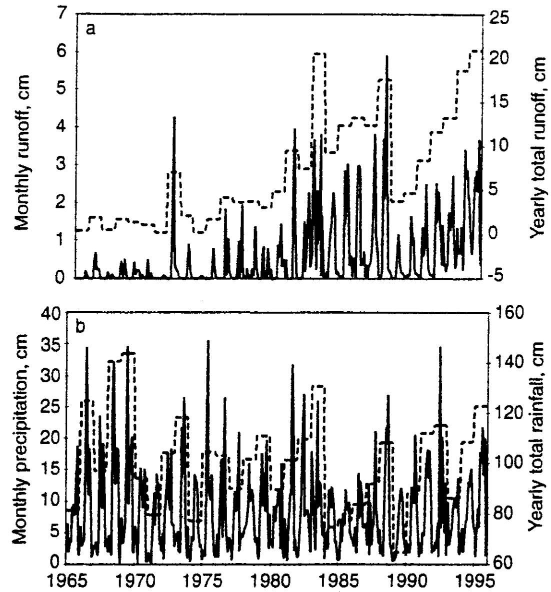

Figure 6. (a) Monthly runoff into Florida Bay was estimated from measured discharges in Taylor Sough (1965 to 1995) and in the C111 canal (1970 to 1995). The volumetric fluxes were divided by the surface area of Florida Bay (200 km^2) to yield an equivalent bay-wide depth for runoff. The dashed line is the total runoff for each calendar year. (b) Monthly rainfall onto Florida Bay for 1965 to 1995 was estimated from relationships between long-term rainfall data in the Everglades and more recent (short term) rainfall data in Florida Bay. The dashed line is the total rainfall for each calendar year.

$$S_{\text{ann}} = S_{\text{ocn}} \frac{Q_T}{Q_T + Q_F}, \tag{7}$$

where $Q_F = Q_P + Q_R - Q_E$ and the rainfall, runoff, and evaporation fluxes are annual average values.

We applied the box model separately to each of the four regions in the bay (Figure 3). Annual runoff and rainfall volumes (Figure 6) were uniformly distributed over the entire area of the bay. In the case of runoff we assumed that mixing within the bay was vigorous enough to redistribute runoff throughout the bay from its localized points of discharge in less than a year. In the case of rainfall the available records from points within the bay were insufficient to characterize any spatial distribution that was not uniform. We thus applied the same rainfall, Q_P, and runoff, Q_R, to each region, and we

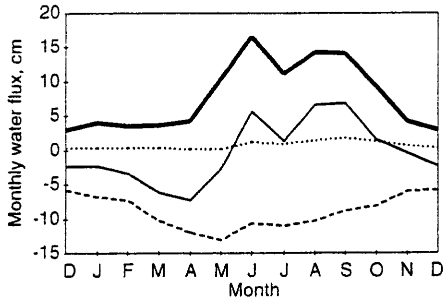

Figure 7. Average monthly freshwater fluxes to Florida Bay for 1970 to 1995. The net freshwater supply (fine line) fluctuates between deficit and surplus because peaks in monthly patterns of rainfall and runoff (bold and dotted lines) lag the peak in monthly evaporation (dashed line) by about 4 months.

calibrated the unknown annual exchange fluxes, Q_T, and annual evaporation fluxes, Q_E, for each region by individually fitting the model to the observed salinity data (using least squares minimization of the residuals). Following calibration for each region, we calculated the annual, bay-wide evaporation rate, E_B, as the average of the four regional values of Q_E (see (6)).

3.4.2. Dynamic, spatially explicit model. We used a dynamic, spatially explicit mass balance model to investigate the combined influence of seasonal and interannual variations in net freshwater supply for two reasons. We needed a dynamic model because residence times in the bay exceed 1 month and we could not assume a steady state salinity response on a seasonal or monthly timescale. We needed a spatially explicit model to examine whether the influence of runoff on a monthly scale would be confined to basins near the inflow along the Everglades coast. We developed a model for this purpose that maintains a running account of the water and salt budgets in each of 44 well-mixed basins within the bay (Figure 3). The boundaries of these basins follow the system of the anastomosing banks that dissect the bay. This geometry was chosen because the banks are the primary controls on fluxes within the bay and the basins offer a natural framework for mass balance accounting. This approach traces its roots to the *Keulegan*'s [1967] model for the response of a coastal lagoon to forcing by ocean tides acting through an inlet. Tidal exchange through the inlet is modeled using Manning's equation and the head difference between zero-velocity water bodies at either end of the inlet channel. We adapted this approach to conditions in Florida Bay where exchange is governed by the constriction of shallow banks, not narrow inlets, and we extended it to a network of basins interconnected by flows over banks.

The dynamic mass balance model (Flux Accounting and Tidal Hydrology at the Ocean Margin (FATHOM)) calculates exchange with a coastal ocean and mixing among basins in a bay as the results of tidally driven water fluxes across shallow banks. At each hourly time step the model solves for uniform, hydraulic flow across each bank based on the depth, width, and frictional roughness of the bank and water levels in upstream and downstream basins. Manning's equation for friction flow in channels [see *Henderson*, 1966] is used to calculate water velocity as a function of depth with a vertical resolution of 0.3 m. These velocities are used with cross-sectional areas of banks to calculate water fluxes. Salt fluxes are then calculated from water fluxes and the salinity of an "upstream" basin. Details of the banks' representation and the hydraulic-equation solutions are given by *Cosby et al.* [1999]. Basically, FATHOM simulates mixing of salt between adjacent basins as tidally driven flows over a series of weirs.

In addition to the climate data needed for the box model, FATHOM requires tide data to set the open-water boundary conditions for the bay. Hourly tide stages along the Gulf of Mexico and Atlantic boundaries of Florida Bay were interpolated from NOAA tide tables for locations along the southern Florida coast and along the Florida Keys. We used semidiurnal tides and applied the same annual pattern for all years from 1965 to 1995. The effects of wind tides and wind mixing were not included in this application of FATHOM. We assumed the Gulf of Mexico and Atlantic salinity to be constant at 35. The seasonal estimates of evaporation derived from the box model (equation (6)) were applied using the same total evaporation and seasonal pattern for all basins and all years simulated. Our estimated monthly rainfall for the bay (Figure 6b) was evenly distributed over the 44 basins, and monthly runoff (Figure 6a) was added at five inflow points along the north shore of the East Region. Runoff distribution among the inflow points was determined by the proportions of the total runoff contributed by measured flows in Taylor Slough and the C111 canal. Generally, the influence of the C111 canal has been to redistribute runoff to the easternmost parts of the northern boundary [*Lorenz*, 1999] relative to historical conditions. We derived the length/depth distribution of each bank and the volume/depth distribution of each basin from Geographic Information System (GIS) data that had a resolution of 20 m. On the basis of this GIS data we assigned to each bank one of four widths (300, 1000, 3000, or 4000 m). We applied a value of 0.1 for Manning's n, the friction coefficient, for all banks (based on the literature for sediments and substrates similar to those on the banks in Florida Bay [e.g., *Henderson*, 1966]).

FATHOM calculates hourly values of water level and mean salinity for each basin; monthly average salinity was calculated for each basin based on these hourly values. Because of the simplifying assumptions inherent in the representation of tidal exchange in the model, the variation of salinity is not correctly represented at timescales less than that represented in the variation of monthly average salinity. For all but the East Region (which consists of a single basin), simulated monthly salinity values from two adjacent basins were averaged to provide regional salinity estimates that corresponded to the observed data (Figure 3). We did not calibrate FATHOM in any formal sense (e.g., optimization by least squares to fit the salinity data). The inputs described above were applied to the model, and the simulated salinity values were used without further adjustment.

4. Results and Discussion

4.1. Water Balance for Florida Bay

Using the annual averages of rainfall and runoff for 1970 to 1995 estimated from our data for these inputs (Figure 6) and the annual evaporation estimated from the application of the box model to the salinity data for 1987 through 1995 (see section 4.1.2), we derived an annual water balance for Florida Bay for rainfall of 98 cm yr^{-1}, for runoff of 9 cm yr^{-1}, for evaporation of 110 cm yr^{-1}, and for net freshwater supply to the bay of -3 cm yr^{-1}. We averaged the freshwater fluxes for each month from 1970 through 1995 to derive an average seasonal cycle of the water balance for Florida Bay (Figure 7).

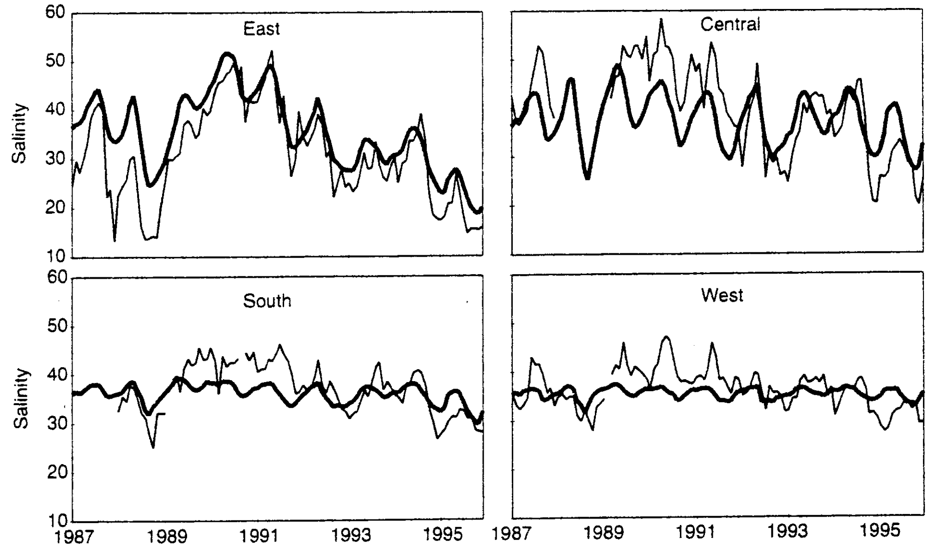

Figure 9. The simulated salinity values from the Flux Accounting and Tidal Hydrology at the Ocean Margin (FATHOM) model (bold line) when compared to the observed salinity data (fine line) for 1987 to 1995 revealed the magnitude of salinity variations associated with both interannual and seasonal variations in rainfall and runoff for each aggregated basin in Florida Bay. FATHOM was driven by monthly rainfall and runoff and simulated the salinity for all four basins over the 9 years with an efficiency of 51%.

component to runoff in FATHOM; all runoff was applied to the small bays along the northeastern margin of the bay that border the East Region (Figure 3), and no runoff was applied directly to the Central Region. This agreed with the location of the sources of runoff (Figure 1) and contrasted to the way runoff was applied in the box model (uniformly to all regions). Because of the increased spatial resolution and seasonal nature of the inputs, FATHOM simulated salinity in the East and Central Regions much more successfully than did the box model. However, FATHOM did not simulate the salinity variations observed in the West Region with the same success. The West Region is adjacent to the boundary with the Gulf of Mexico where salinity in the model was assumed to be constant. However, salinity does vary in the gulf adjacent to the bay, and the lack of this source of variation in the model contributed to the discrepancy.

Taken together, these seasonal results and the results from the annual analysis of net freshwater supply suggested that variations in the net freshwater supply influenced salinity in Florida Bay at both the seasonal and interannual timescales. Three factors, (1) location within the bay, (2) interannual variation of rainfall and runoff, and (3) seasonal variation of runoff and precipitation, accounted for approximately 51% of the observed salinity variation in the bay, each component contributing approximately equally (16%, 21%, and 14%, respectively). Other important sources of variation not included in these analyses, but which might have explained much of the remaining 49% of salinity variation, were temporal and spatial patterns of evaporation, wind-driven mixing and exchange with the coastal ocean, spatial patterns of rainfall over the bay, and variations of salinity at the Gulf of Mexico and Atlantic boundaries of the bay.

4.3. Model Reconstructions of Long-Term Salinity Variations (1965–1995)

We compared simulation results from each model with salinity observations from the complete 31-year (1965–1995) database to assess the predictive ability of the models. The 31-year record contains the temporally dense data used to calibrate the models (9 years from 1987 to 1995 comprising approximately 50% of the observations) and a sparser record that contains approximately the same number of observations over a longer period (22 years). Our purpose was not so much to formally test the models (that would have required that we evaluate only that data not used in calibration) as it was to extend the models to identify critical areas in which improvements could be made to both models and the supporting data.

The location model, based on regional means of the evaluation period (1987 through 1995), attained an efficiency of 20% when applied to the complete 31-year record (Table 4). This was not much different from the 16% efficiency achieved for the evaluation period and suggested that the effects of location have not changed much over the 3 decades under consideration. Likewise, efficiency for the steady state box model applied to all of the data was not significantly different from the box model efficiency achieved on the evaluation period (Table 4). We inferred from this that patterns of interannual variations in freshwater fluxes and the patterns of response in annual average salinity were relatively uniform over the period.

However, the efficiency score for FATHOM decreased from 51% when applied to the shorter evaluation period to 28% for the complete 31-year period probably because of the data used to drive the models and the salinity data itself. Since the efficiency for FATHOM declined even though the efficiencies of the other models did not, the quality and quantity of the data for the earlier period specific to FATHOM must have differed from that in the later evaluation period. These kinds of data include spatially explicit patterns of rainfall and runoff, monthly patterns of freshwater fluxes, and temporal and spatial variations in salinity values along the Gulf of Mexico and Atlantic Ocean boundaries. Given that FATHOM was the most spatially and temporally complex of the models, it should

Monthly rainfall varied from about 4 cm month^{-1} during the dry season to greater than 15 cm month^{-1} at the peak of the rainy season. Estimated evaporation was lowest in winter (about 6 cm month^{-1}) and reached a peak in early summer (13 cm month^{-1}). Monthly runoff under the management practices in place during the period was uniformly low (less than 2 cm month^{-1} for all months), but there appeared to be a tendency toward slightly higher runoff in late summer (Figure 7).

4.1.1. Importance of rainfall. Under water-management practices from 1970 through 1995 the average annual volume of runoff into Florida Bay was less than one tenth of the average annual volume of direct rainfall onto the bay. This distinguishes Florida Bay from other nearby estuarine areas where the ratio of runoff to direct rainfall was 1 to 2 orders of magnitude greater (Table 2). Within the bay the effects of runoff can be locally more important. For instance, in the East Region where almost all direct runoff actually entered the bay, the ratio of runoff to rainfall was larger (approximately 0.5). Comparing salinity conditions in the East Region with those in the Central Region provided an indication of the spatial variation in the magnitude of the effect of runoff to rainfall ratios on salinity within the bay. Both regions were relatively isolated from exchange with the ocean, but the Central Region received little freshwater inflow from runoff. Salinity variations in the two regions were similar (and high compared to other areas of the bay), but the mean salinity in the Central Region (no runoff) was 10 higher than that in the East Region (Table 1).

4.1.2. Estimated evaporation. The calibration of the box model for each region in the bay provided an estimate of annual average evaporation in each region for 1987 through 1995 (Table 3). We averaged the evaporation rates for each region to estimate the annual evaporation rate for Florida Bay as a whole. This average annual, bay-wide evaporation rate was approximately 110 cm yr^{-1}, significantly lower than the estimates derived from the pan data at Flamingo (210 cm yr^{-1}) and the water budget for Lake Okeechobee (162 cm yr^{-1}). Within the bay the estimates of annual evaporation varied spatially (Table 3). The estimated rates were almost identical in the Central, South, and West Regions (approximately 130 cm yr^{-1}), but the estimated rate for the East Region was more than 30% lower. A spatial pattern in evaporation over the bay (related to water depth, bottom cover, etc.) was expected, and, theoretically, the calibration of the box model could recover some of that pattern (to the degree to which the pattern is reflected in the annual average salinities used to calibrate the model).

Table 2. Comparison of Annual Freshwater Input Fluxes for Florida Bay With Other Florida Estuaries

Estuary	Area, km^2	Runoff,[a] cm	Rainfall,[a] cm	Inflow,[a] cm	Runoff/ Rainfall
Florida Bay[b]	2000	9[c]	98	107	0.1
Charlotte Harbor[d]	700	430	143	573	3.0
Indian River Lagoon[e]	568	635	131	766	4.8

[a]Annual volume is divided by area of estuary.
[b]Runoff and rainfall are annual averages for 1970 through 1995.
[c]This is the sum of gauged flows in Taylor Slough and in the C111 canal at S18C.
[d]Source is *Miller and McPherson* [1991].
[e]Source is *Smith* [1993].

Table 3. Summary of the Box Model Calibration for 1987–1995

Basin	Tide,[a] cm	Q_T,[b] cm yr^{-1}	Q_E,[b] cm yr^{-1}	r^2
East	0	172	83	0.25
South	6	339	128	0.48
Central	1	198	129	0.67
West	8	345	122	0.63

[a]Source is N. P. Smith and P. A. Pitts (Harbor Branch Oceanographic Institution, unpublished report, 1996).
[b]Values of Q_T and Q_E were estimated during calibration by nonlinear regression using observed annual average salinity.

The box model explained a much smaller proportion of the variation in the annual average salinity values in the East Region than elsewhere in the bay (based on the r^2 values, Table 3). The lower estimated evaporation and the lower explained variance in the east may reflect an underestimation of the freshwater fluxes either from runoff or direct rainfall into this region. This underestimation probably resulted, at least in part, from our decisions (1) to apply annual runoff uniformly to each region under the assumption that mixing of runoff throughout the bay was complete within a year and (2) to ignore the effect of rainfall contributions from the Taylor Slough area below the discharge gauge. If most of the runoff (and some additional rainfall) had been added to the simulations for the East Region, the estimated evaporation (and perhaps the explained variance) would have been higher in that region. Adding less runoff to the other regions would have resulted in lower estimated evaporation rates. Lacking observations on distribution and mixing of runoff in the bay (and the necessary resolution in the steady state, spatially aggregated box model structure), we could not evaluate these potential biases in the regional evaporation estimates. We therefore averaged the annual evaporation rates from all four regions to provide our best, unbiased estimate of the bay-wide annual evaporation rate.

4.2. Influence of Net Freshwater Supply on Salinity

4.2.1. Sources of interannual variation. The average annual net freshwater supply to Florida Bay is essentially zero. However, there have been large fluctuations in both the annual rainfall and annual runoff to the bay (Figure 6). From 1965 to 1995, annual direct rainfall onto the bay varied from about 75 cm yr^{-1} to about 140 cm yr^{-1}, a range of interannual variation of 65 cm yr^{-1} (range is 65% of mean value). For the same period the range of interannual variation of runoff into the bay was only 23 cm yr^{-1} (from 0 to 23 cm yr^{-1} with a range of 250% of mean value). Given the absolute magnitudes and ranges of interannual variations of rainfall and runoff, it seems likely that annual variations of salinity in Florida Bay for the last 3 decades have been primarily affected by variations in annual rainfall and only to a lesser extent by changes in annual runoff even though the percentage of changes in runoff have been greater.

4.2.2. Results of the steady state model. A comparison of the annual average salinity values simulated by the steady state box model with the observed monthly salinity data supported our conclusion that interannual variations in rainfall and runoff explained much of the variation of salinity in all regions of the bay (Figure 8). The box model, which was applied to each

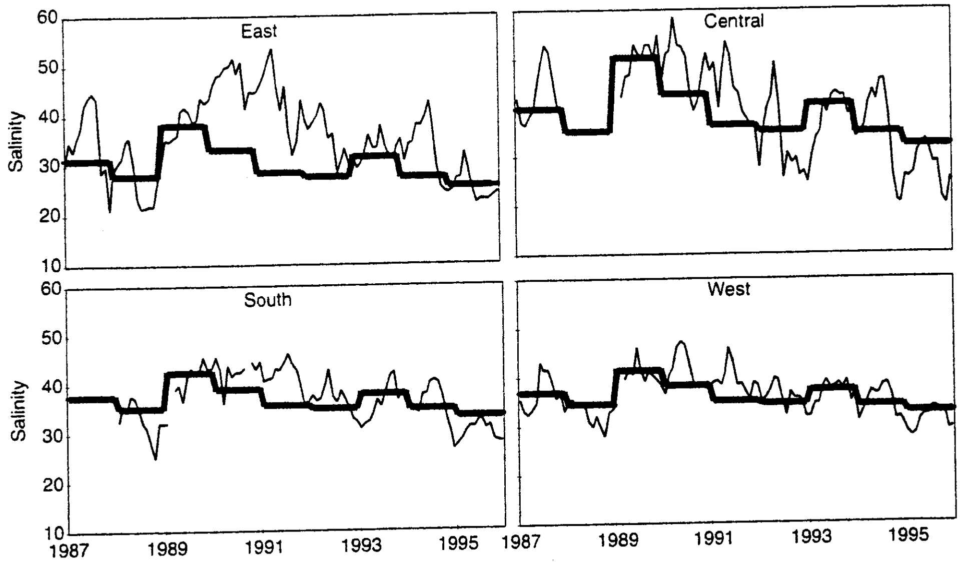

Figure 8. The simulated salinity values from the box model (bold line) when compared to the observed salinity data (fine line) for 1987 to 1995 revealed the magnitude of salinity variations associated with interannual variations in rainfall and runoff for each aggregated basin in Florida Bay. The box model was driven only by annual rainfall and runoff and simulated the salinity of all four basins over the 9 years with an efficiency of 37%.

region using annual fluxes, attained an efficiency of 37% for 1987 through 1995 (Table 4). (For each region the simulated average salinity for a given year was used for all months within that year when calculating the efficiency by (2).) By contrast, the efficiency score for the location model, the long-term mean salinity for each region, was just 16% (Table 4). (For each region the mean salinity was used for all months in all years when calculating the efficiency by (2).) The difference in efficiency can be attributed to the influence on salinity of interannual fluctuations in rainfall and runoff. That is, approximately 21% of the variance of salinity in Florida Bay resulted from interannual variations of freshwater fluxes.

The values of the exchange flux, Q_T, in the box model can be interpreted as the water renewal rate, a function of tidal exchange with the Gulf of Mexico and the Atlantic. We compared the magnitudes of the calibrated exchange fluxes with observed tidal amplitudes in each region of the bay (Table 3) and found a strong correlation, providing partial, qualitative corroboration of the model calibration. The calibrated values of Q_T (Table 3) were used to estimate residence times in each region of the bay. Assuming that the average water depth in each region is 100 cm, residence times in years were defined as $100/Q_T$. These estimates of residence times ranged from 0.3 to 0.6 years and indicated that water in the East and Central Regions would require over a year to be completely replaced by exchange flux. The results of the residence time analysis and the fact that observed fluctuations in the salinity data appear to lag the simulated salinity (Figure 8) for all regions suggested that annual average salinity was not in steady state with annual variations in the net freshwater supply anywhere within the bay.

4.2.3. Seasonal effects. On a monthly basis the average net freshwater supply fluctuated considerably between negative and positive values (Figure 7). The average net supply of freshwater was positive during the rainy season (from June through October) and was negative in the winter and spring. Generally, salinity values during winter and spring exceeded the salinity of the adjacent ocean; during the rainy season, salinity values dropped to below ocean salinity (Figure 5). Although annual runoff was small compared to annual rainfall, the seasonal variation in runoff was an important component of the seasonal variation in net freshwater supply. For example, total net freshwater supply during the rainy season was about 22 cm, of which more than 30% was contributed by runoff from Taylor Slough and the C111 canal. This implies that changes in the amount or the timing of the seasonal components of runoff may have greater impact than changes in annual totals alone.

4.2.4. Results from the dynamic model. FATHOM attained an efficiency score of 51% when compared to salinity observations for 1987 through 1995, compared to 37% attained by the steady state box model (Table 4). This suggested that approximately 14% of the variance in observed salinity in Florida Bay was related to seasonal variations in net freshwater supply. The increased efficiency largely resulted because FATHOM very successfully simulated both the seasonal fluctuations and interannual trends in salinity observations in the East and Central Regions (Figure 9). There was a spatial

Table 4. Types of Variability in Salinity Derived From Comparison of Model Results

Types of Variability[a]	Model	Efficiency (Eff), % 1987–1995	Efficiency (Eff), % 1965–1995
Spatial	basin means	16	20
Spatial and interannual	box model	37	38
Location, interannual and seasonal	FATHOM	51	29

FATHOM is Flux Accounting and Tidal Hydrology at the Ocean Margin model.
[a]Variability categorized as spatial (among basins, interannual), based on annual averages, and seasonal, based on monthly averages.

Table 5. Sensitivity of Monthly Average Salinity Simulated by FATHOM to Increased Runoff From 1987 to 1995

Basin	Reference Simulation		Runoff Doubled	
	Mean	SD	Mean	SD
East	35.4	8.0	26.1	8.9
South	36.0	2.0	35.0	2.8
Central	37.5	5.3	37.2	5.7
West	35.3	1.1	35.3	1.2

SD is standard deviation.

not have been surprising that its efficiency declined as it was applied to the earlier periods where the salinity data were sparse and flux data were increasingly uncertain. For example, a program of regular salinity monitoring has only been in place since about 1990; data from before this date are largely compilations of incidental measurements. Also, rainfall measurements from in the bay were only available from 1991. Before that, monthly values of rainfall were extrapolated from land-based stations based on regression equations calibrated on the 4 years of recent data in the bay. The exact cause(s) of the salinity variations in Florida Bay in the 1960s and 1970s may never be known.

4.4. Critical Gaps in Knowledge

Our analyses of net freshwater supply and our model reconstructions of long-term salinity variations have identified several areas where better information would improve our understanding of and ability to predict salinity variations in Florida Bay. Generally, these areas can be grouped as uncertainties relating to (1) complete lack of direct information about the magnitude and the spatial and temporal variations in evaporation in the bay; (2) insufficient long-term and seasonal data on both terrestrial and oceanic boundary conditions of the bay; and (3) the poor temporal and spatial coverage by currently available measurements of direct rainfall into the bay.

For example, the first two of these relate to the unknown causes of the lower evaporation rate estimated by the box model for the East Region (Table 3). Using the available information, we could not ascertain if the lower rate simply reflected the spatial variations in evaporation that we knew must be present in the bay (but which had not been quantified) or if the lower rate arose because we did not account for direct rainfall onto and runoff from the wetlands south of the Taylor Slough and C111 canal discharge measurement points. In either case a significant freshwater flux pertinent to the northeastern bay remains unquantified. The results of *Corbett et al.* [1999] rule out the possibility that this unknown source could be submarine groundwater discharge.

Another area of uncertainty about boundary conditions relates to salinity variations along the Gulf of Mexico and Atlantic boundaries of Florida Bay. In our models we assumed this salinity was constant and equal to 35. However, freshwater discharge from Shark Slough (Figure 1) joins a southward flowing coastal current just north of Florida Bay and contributes to salinity variation at the northwestern boundary of the bay. Recent data from this area have documented salinity fluctuations of 26 to 39 [e.g., *Boyer et al.*, 1999; *Wang*, 1998].

4.5. Simulated Response to Increased Runoff

Even with the limitations of the data and the current model, FATHOM simulated salinity variations for 1987 to 1995 reasonably well (Figure 9). We therefore decided to use this FATHOM application as a reference case and to investigate the sensitivity of salinity in Florida Bay to changes in runoff from Taylor Slough and the C111 canal. The experiment reported here was relatively simple and is presented only to demonstrate the usefulness of the model in such exercises and to provide a rough measure of the responses of salinity in Florida Bay to changes in the management of freshwater runoff into the bay.

We conducted a model simulation in which monthly runoff rates for every month from 1987 through 1995 were doubled. Monthly rainfall and evaporation rates were not changed. The increased runoff was applied to the model in the same locations (i.e., only the volume of runoff was increased, the spatial distribution of runoff was not changed). The results of this experiment were compared to the reference simulation (Table 5). In the East Region the increased runoff depressed the mean salinity value by 9.3 below the mean for the reference simulation. In the south, although the mean salinity was little changed, the standard deviation of monthly salinity values increased 40% (Table 5). Rather importantly for some management options under consideration, doubling runoff without changing its distribution along the northern boundary of the bay had little effect on salinity in the Central Region. This is significant because salinity in excess of 60, which occurs for short periods in the Central Region [*Fourqurean et al.*, 1993] even though monthly means do not show it (Figure 8), is often implicated in the ecological decline in the bay. Our experiment simply doubled the runoff for all months. Our analysis of the seasonal patterns in net freshwater fluxes suggested that the same total annual volume of runoff increase, if applied in just a few properly chosen months (instead of in all months), would have a much larger effect on salinity in the bay. Management options for ecosystem restoration in the Everglades and Florida Bay could certainly include changes in the timing as well as amount of runoff. Our analysis of the effects of location in the application of runoff also suggested that changing the runoff points along the Everglades boundary would affect the distribution of the freshwater within the bay. For instance, the redistribution of runoff westward from the C111 canal into Taylor Slough should bring larger salinity changes in the Central Region. We plan to continue to use FATHOM to investigate the projected effects of various changes in runoff amount, location, and timing on salinity distributions in Florida Bay.

5. Conclusions

The annual average water balance for Florida Bay from 1970 to 1995 was dominated by rainfall and evaporation, which were approximately equal. Annual runoff was less than one tenth of rainfall. Annually, the variations of salinity in Florida Bay for the last 3 decades have been primarily affected by interannual variations in rainfall volumes and somewhat less by changes in annual runoff even though the relative changes in runoff over the period have been greater.

Variations in the net freshwater supply influence salinity in Florida Bay seasonally and interannually. Three factors (location within the bay, interannual variation of rainfall and runoff, and seasonal variations of runoff and precipitation) accounted for approximately 51% of the observed salinity variation in the bay from 1987 to 1995, each component contributing approximately equally (16%, 21%, and 14%, respectively). Other important sources of variation not in these analyses but that might have explained much of the remaining 49% of the salinity variation were temporal and spatial patterns of evaporation, wind-driven mixing and exchange with the coastal ocean, spatial patterns of rainfall over the bay, and variations of salinity at the Gulf of Mexico and Atlantic boundaries of the bay.

We identified several areas where better information would improve our understanding of and ability to predict salinity variations in Florida Bay. Generally, these areas could be grouped as uncertainties relating to (1) complete lack of direct information about the magnitude and the spatial and temporal variations in evaporation in the bay; (2) insufficient long-term and seasonal data on both terrestrial and oceanic boundary conditions of the bay; and (3) poor temporal and spatial coverage by currently available measurements of direct rainfall into the bay.

Appendix: Florida Bay Historical Salinity Database

Salinity measurements for Florida Bay are numerous but scattered, reflecting the diverse character of the biologic, geologic, and hydrologic studies that generated the data. The available salinity record for Florida Bay began in 1936. Prior to this, salinity observations were extremely rare, and references to salinity conditions in the Florida Bay were mostly qualitative. By the mid-1950s, spatially and temporally intensive data were becoming available, but they were scattered in space and time. In 1981 the National Park Service inaugurated routine salinity monitoring in Florida Bay; by 1988 this network had become sufficiently dense to meet many of the needs of management and science.

We compiled into a single database what we feel are the most reliable salinity data for Florida Bay available in both published and unpublished sources. Temporal coverage of the database was reasonable, with a number of studies available in each decade since 1940 (Table A1). Spatial coverage was reasonable in most areas, but in some areas no data were available. For instance, few data were available covering the extensive shallow water banks in western Florida Bay primarily because the area is inaccessible by boat. We searched extensively for any source of data prior to 1990. For the data since 1990 we limited our sources to several spatially and temporally intensive monitoring studies in the bay. Regardless of the source, a salinity measurement was only included in the database if it met the following criteria: (1) The observation was made within Florida Bay or in waters immediately adjacent to the bay. (2) The measurement was a discrete observation (i.e., the observation was not part of a high-frequency time series or an average value taken over time or space). (3) The date and time of the observation were known. (4) The latitude and longitude of the location of the observation were available or could be estimated. (5) The depth at which the observation was made could be determined (i.e., surface, bottom, or intermediate depth).

Currently, the database contains over 34,000 salinity observations covering 1947 to 1995. Data sources in this compilation are organized by "study numbers" from 1 to 60. Each study consists of salinity measurements drawn from a single or a few closely related sources. Table A2 summarizes the number of stations, number of measurements, location, and duration (dates) of each study and includes references to the published or unpublished literature from which the data were extracted.

Table A1. Chronology of the Studies Included in the Historical Database for Florida Bay

	Decade					
Study	1940	1950	1960	1970	1980	1990
2	x					
4		x				
7		x				
8		x				
28		x	x			
34		x	x			
5			x			
6			x			
16			x			
22			x		x	
26			x			
29			x			
35			x			
41			x			
43			x			
55			x			
59			x			
3				x		
9				x		
12				x		
13				x	x	
14				x	x	
19				x	x	
21				x		
42				x		
45				x		
49				x	x	x
51				x		
54				x	x	
57				x		
1					x	
10					x	
15					x	
17					x	
20					x	
23					x	x
24					x	
25					x	x
27					x	x
30					x	x
31					x	x
32					x	x
33					x	x
36					x	
38					x	
46					x	x
47					x	x
48					x	
50					x	
52					x	x
58					x	x
18						x
37						x
39						x
60						x

Table A2. Annotated Bibliography

Study	Location	Number of Stations	Number of Observations	Period Sampled	Reference
1	NW Florida Bay, Shark River	8	50	Mar. 1984 to Sept. 1985	Powell, A. B., D. E. Hoss, W. F. Hettler, D. S. Peters, L. Simoneaux, and S. Wagner, Abundance and distribution of ichthyoplankton in Florida Bay and adjacent waters, *SFRC-87/01*, 45 pp., S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1987.
2	west coast estuaries, north, central, NE Florida Bay	31	31	June 1947 to May 1948	Davis, C. C., Notes on the plankton of Long Lake, Dade County, Florida, with descriptions of two new copepods, *Q. J. Fla. Acad. Sci., 10*, 79–88, 1948.
3	Long Sound, Manatee Bay	14	30	Jan. 1977 to March 1977	Creamer, D., Salinity observations east and west of U.S. Highway 1, unpublished report, Fish and Wildl. Serv., Vero Beach, Fla., 1977.
4	nearshore Gulf of Mexico, west coast estuaries, NW Florida Bay, Whitewater Bay	48	1225	Mar. 1954 to June 1958	Dragovitch, A., J. H. Finucane, and B. Z. May, Counts of red tide organisms, *Gymnodinium breve*, and associated oceanographic data from Florida west coast, 1957–1959, *Spec. Rep. Fish 369*, pp. 1–102, U.S. Fish and Wildl. Serv., Vero Beach, Fla., 1961. Finucane, J. H., and A. Dragovitch, Counts of red tide organisms, *Gymnodinium breve*, and associated oceanographic data from Florida west coast, 1957–1959, *Spec. Rep. Fish 289*, pp. 202–295, U.S. Fish and Wildl. Serv., Vero Beach, Fla., 1959. Finucane, J. H., Distribution and seasonal occurrence of *Gymnodinium breve* on the west coast of Florida, 1954–57, *Spec. Sci. Rep. Fish 487*, 14 pp., U.S. Fish and Wildl. Serv., Vero Beach, Fla., 1964.
5	Buttonwood Sound	19	75	Aug. 1962 to Feb. 1963	Lynts, G. W., Relationship of sediment-size distribution to ecological factors in Buttonwood Sound, Florida Bay, *J. Sediment Petrol., 36*(1), 66–74, 1966.
6	Florida Bay, Florida Keys	8	2140	Mar. 1960 to Jan. 1961	Goodell, H. G., and D. S. Gorsline, Data report on the hydrography of Apalachicola and Florida Bays, *Fla. St. Univ. Sed.Res. Lab. Contrib. 1*, 316 pp., Fla. State Univ., Tallahassee, 1961.
7	Florida Bay, Florida Keys	32	54	Aug. 1958 to Jan. 1959	Lloyd, R. M., Variation in oxygen and carbon isotope ratios of Florida Bay mollusks and their environmental significance, *J. Sediment Petrol., 36*(1), 84–111, 1964.
8	central, east Florida Bay	76	615	Dec. 1956 to April 1958	McCallum, J. S., and K. S. Stockman, Salinity in Florida Bay, *Geol. Misc. 21*, 14 pp., Explor. and Prod. Res. Div., Shell Dev. Co., Houston, Tex., 1959.
9	east, central Florida Bay, Barnes Sound, Manatee Bay	166	1760	Jan. 1977 to Feb. 1979	Coleman, R. A., T. W. Schmidt, R. E. Hermance, P. W. Rose, P. C. Patty, W. B. Robertson Jr., Some hydrographic aspects of the estuarine area from northeastern Florida Bay to Barnes Sound, especially in restoring historical water conditions, unpublished management report, 41 pp., S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1979.
10	west, central Florida Bay	5	40	Nov. 1982 to Dec. 1986	Powell, G. V. N., S. M. Sogard, and J. G. Holmquist, Ecology of shallow water bank habitats in Florida Bay, final report to S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 406 pp., Ornithol. Res. Unit, Natl. Audubon Soc., Tavernier, Fla., 1987.
11	NE Florida Bay	67	77	Feb. 1967 to Mar. 1967	Tabb, D. C., T. R. Alexander, T. M. Thomas, and N. Maynard, The physical, biological, and geological character of the area south of the C-111 Canal in extreme southeastern Everglades National Park, Homestead, Fla., final report, (contract 14-10-1-160-11), S. Fla. Res. Cent., Natl. Park Serv., Homestead, Fla., 1967. (Available as *ML 67103*, Rosenstiel Sch. of Mar. and Atmos. Sci., Univ. of Miami, Miami, Fla.)
12	Florida Bay	49	1665	April 1973 to Sept. 1976	Schmidt, T. W., Ecological study of fishes and the water quality characteristics of Florida Bay, Everglades National Park, Florida, final report, 144 pp., S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1979.
13	east, north, central Florida Bay	262	3070	July 1978 to Sept. 1983	White, D. A., Oceanographic monitoring study, October 1980 to October 1983, unpublished report, S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1983.
14	Florida Bay	13	275	Mar. 1977 to June 1980	Bert, T. M., J. T. Tilmant, J. W. Dodrill, and G. E. Davis, Aspects of the population dynamics and biology of the stone crab (*Menippe mercenaria*) in Everglades and Biscayne National Parks as determined by trapping, *Tech. Rep. SFRC-86/04*, 77 pp., S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1986.
15	east, NW Florida Bay, Whitewater Bay	30	160	Feb. 1982 to Dec. 1983	Rutherford, E. S., Larval and juvenile gamefish study, February 1982 to December 1983, unpublished report, S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1983.
16	NW Florida Bay	1	16	Jan. 1963 to Dec. 1964	Overstreet, R. M., Parasites of the inshore lizardfish, *Synodus foetens*, from south Florida, M.S. thesis, 69 pp., Univ. of Miami, Miami, Fla., 1966.

Table A2. (continued)

Study	Location	Number of Stations	Number of Observations	Period Sampled	Reference
17	NE Florida Bay	12	221	Mar. 1986 to Sept. 1987	Montague, C. L., R. D. Bartleson, and J. A. Ley, Assessment of benthic communities along salinity gradients in northeastern Florida Bay, *Final Rep. CA5280-5-8004*, S. Fla. Res. Cent., Natl. Park Serv., Homestead, Fla., 1989. (Available from Rosenstiel Sch. of Mar. and Atmos. Sci., Univ. of Miami, Miami, Fla.)
18	west, central Florida Bay, Sunset Cove	50	350	June 1990 to Nov. 1991	Robblee, M. B., Salinity and temperature data collected at swim-over stations associated with sea-grass die-off monitoring, 1990 to 1991, unpublished data, S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1991.
19	east Florida Bay	7	96	Oct. 1979 to Nov. 1980	Evink, G. L., Hydrological study in the area of Cross Key, Florida, *Environ. Res. FL-ER-16-81*, 31 pp., Fla. State Dep. of Transp., Bur. of Environ., Tallahassee, Fla., 1981.
20	west, central, south Florida Bay, Whitewater Bay	205	274	May 1984 to June 1985	Thayer, G. W., W. F. Hettler Jr., A. J. Chester, D. R. Colby, and P. T. McElhaney, Distribution and abundance of fish communities among selected estuarine and marine habitats in Everglades National Park, *Tech. Rep. SFRC-87/02*, 166 pp., S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1987.
21	central, east Florida Bay	43	75	June 1970 to Sept. 1973, Mar. 1977	Ogden, J. C., Field notes associated with Florida Bay field trips from Tavernier, Florida, 1971 to 1973, 1977, Ornithol. Res. Unit, Natl. Audubon Soc., Tavernier, Fla., 1977.
22	Florida Bay, Barnes Sound, Manatee Bay	312	312	May 1966, Jan. 1984 to June 1984	Shaw, A. B., Salinity data collected from across Florida Bay associated with studies of the distribution of mollusk shells, maps, Amoco Oil, Chicago, Ill., 1984.
23	west, central Florida Bay	47	230	May 1989 to Dec. 1991	Robblee, M. B., Salinity and temperature data associated with benthic animal sampling of seagrass die-off impacted areas in Florida Bay, 1989 to 1991, unpublished data, S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1992.
24	east, central, west Florida Bay, Manatee Bay	96	180	Aug. 1988 to Oct. 1988	Robblee, M. B., and J. W. Fourqurean, Field notes associated with the August 1988 C-111 canal water release, unpublished data, S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1988.
25	Florida Bay, Whitewater Bay, west coast estuaries	38	3190	May 1981 to Dec. 1995	Smith, D. T., Surface refractometer measurements made at marine monitoring stations, 1981 to 1995, unpublished data, S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1995.
26	Florida Bay, Florida Keys	61	610	Aug. 1963 to Feb. 1969	Costello, T. J., D. M. Allen, and J. H. Hudson, Distribution, seasonal abundance, and ecology of juvenile northern pink shrimp, *Penaeus duorarum*, in Florida Bay area, *NOAA Tech. Memo. NMFS-SEFC-161*, 84 pp., Natl. Oceanic and Atmos. Admin., Miami, Fla., 1986. Hudson, J. H., D. M. Allen, and T. J. Costello, The flora and fauna of a basin in central Florida Bay, U.S. Fish Wildl. Serv., *Spec. Sci. Rep. Fish 604*, 14 pp., Washington, D. C., 1970.
27	Florida Bay, Whitewater Bay	163	815	Oct. 1981 to Oct. 1987	Robblee, M. B., and T. W. Schmidt, Environmental data collected in association with collections of pink shrimp, caridean shrimp, and fishes in Florida Bay and Whitewater Bay, 1981 to 1987, unpublished report, S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1987.
28	NW Florida Bay, Whitewater Bay	36	1540	May 1957 to May 1962	Tabb, D. C., D. L. Dubrow, and R. B. Manning, Hydrographic data from the inshore bays and estuaries of Everglades National Park, Florida, 1957–1959, *ML 59253*, 26 pp., The Mar. Lab., Univ. of Miami, Miami, Fla., 1959. Tabb, D. C., and D. L. Dubrow, Hydrographic data, supplement I, from the inshore bays and estuaries of Everglades National Park, Florida, 1959–1962, *ML 62245*, 22 pp., The Mar. Lab., Univ. of Miami, Miami, Fla., 1962.
29	Florida Bay, Whitewater Bay	57	840	Sept. 1964 to July 1967	Tabb, D. C., Prediction of estuarine salinities in Everglades National Park, Florida, by the use of ground water records, Ph.D. dissertation, 107 pp., Univ. of Miami, Coral Gables, Fla., 1967.
30	Long Key	1	4215	Jan. 1981 to Dec. 1995	Swanson, J. W., Salinity, temperature, pH, DO monitoring data from the Keys Marine Laboratory, unpublished data, Fla. Dep. of Environ. Prot., Long Key, 1995 (Sea World, Orlando, Fla., collected data during the period 1981 to 1987.)
31	Florida Bay	30	190	June 1989 to July 1990	Fourqurean, J. W., R. D. Jones, and J. C. Zieman, Processes influencing water column nutrient characteristics and phosphorus limitation of phytoplankton biomass in Florida Bay, Florida, USA: Inferences from the spatial distributions, *Estuarine Coastal Shelf Sci.*, *36*, 295–314, 1993. Fourqurean, J. W., R. D. Jones, and J. C. Zieman, Water quality observations from across Florida Bay (June 1989 to April 1990), report (contracts CA5280-9-8001, CA5280-9-8008, CA5280-0-9009, CA5280-0-9010 and CA5280-8-8007), Univ. of Va., Charlottesville, Fla. Int. Univ., Miami, and S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1991.

Table A2. (continued)

Study	Location	Number of Stations	Number of Observations	Period Sampled	Reference
32	NE, NW Florida Bay	4	203	Dec. 1989 to Nov. 1991	Lorenz, J., Observations made during Ph.D. research in Florida Bay, 1989 to 1991, Univ. of Fla., Gainesville, 1991.
33	east, central Florida Bay, Whitewater Bay, Shark River	44	220	June 1989 to Mar. 1990	Ley, J. A., and C. L. Montague, Influence of changes in freshwater flow on the use of mangrove prop root habitat by fish, report to S. Fla. Water Manage. Dist., 220 pp., Dep. of Environ. Eng. Sci., Univ. Fla., Gainesville, 1991.
34	NW Florida Bay, Buttonwood Canal, Whitewater Bay, nearshore Gulf of Mexico	9	110	Sept. 1957 to Mar. 1962	Tabb, D. C., and D. L. Dubrow, Biological data on pink shrimp, *Penaeus duorarum*, of north Florida Bay and adjacent estuaries in Monroe County, Florida, September 1957–March 1962, unpublished data, *ML 62239*, 89 pp., The Mar. Lab., Univ. of Miami, Miami, Fla., 1962.
35	Florida Bay, Florida Keys	18	355	Jan. 1962 to Dec. 1962	Gorsline, D. S., Final data report marine geology and oceanography of Florida Bay, Apalachicola Bay and vicinity, Florida, observation period January to December 1962, *Rep. USC Geol. 65-1*, Fla. State Univ., Tallahassee, 1965.
36	West, central, east Florida Bay	179	179	Oct. 1987	Robblee, M. B., Salinity observations following Hurricane Floyd in October 1987, unpublished report, S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1987.
37	Florida Bay	31	80	June 1991 to Feb. 1992	Frankovitch, T. A., Epiphyte loads and production on the seagrass, *Thalassia testudinum*, M.S. thesis, 136 pp., Dep. of Environ. Sci., Univ. of Va., Charlottesville, 1996.
38	central Florida Bay	9	9	Oct. 1980	Gaby, R., Environmental observations along a transect across Florida Bay, October 1, 1980, report to Don Miller, Everglades Prot. Assoc., Islamorada, Fla., 3 pp., Connell, Metcalf and Eddy, Inc., Coral Gables, Fla., 1980.
39	Florida Bay, Barnes Sound	13	230	Jan. 1990 to June 1991	Bugden, J., Water quality observations made in Florida Bay, 1990 to 1991, as part of a M.S. thesis on seagrass die-off, Fla. Int. Univ., Miami, 1991.
41	west coast estuaries, Whitewater Bay	40	1495	April 1962 to Mar. 1967	Marshall, A., and R. Jones, Salinity data from Big Cypress and Everglades west coast estuaries, 1962 to 1967, unpublished data, Branch of River Basin Stud., Fish and Wildl. Serv., Vero Beach, Fla., 1967.
42	Card Sound	5	60	Oct. 1971 to Oct. 1972	Smith, R., Abundance and diversity of sponges and growth rates of *Spongia graminea* in Card Sound, Florida, M.S. thesis, 56 pp., Univ. of Miami, Coral Gables, Fla., 1973.
43	Buttonwood Canal Bridge	1	24	Jan. 1963 to Dec. 1964	Waldinger, F. J., Relationships of environmental parameters and catch of three species of the mojarra family (Gerridae), *Eucinostomus gula*, *Eucinostomus argenteus*, and *Diapterus plumeri*, collected in 1963 and 1964 in Buttonwood Canal, Everglades National Park, Florida, M.S. thesis, 68 pp., Univ. of Miami, Coral Gables, Fla., 1968.
44	Little Blackwater Sound, Long Sound	17	50	Feb. and Mar. 1966	Lee, C. C., The decomposition of organic matter in some shallow water, calcareous sediments of Little Blackwater Sound, Florida Bay, Ph.D. dissertation, 106 pp., Univ. of Miami, Coral Gables, Fla., 1969.
45	Florida Keys	5	21	April 1976 to June 1977	Helbling, R. J., Water quality data collected for Permanent Network Monitoring Program, unpublished data, Fla. Dep. of Environ. Regul., Marathon, Fla., 1978.
46	Florida Bay	50	132	June 1989 to Mar. 1991	Zieman, J. C., and J. W. Fourqurean, Water quality observations associated with seagrass die-off research, 1989 to 1990, unpublished data, Univ. of Va., Charlottesville, 1991.
47	Florida Bay, Whitewater Bay, west coast estuaries	75	2800	Jan. 1991 to Dec. 1995	Jones, R. D., Water quality observations in Florida and Manatee Bays and Barnes Sound, 1991 to 1995, unpublished data, (contract MA5280-0-9015), Fla. Int. Univ., Miami, and the S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1991–1995.
48	NE Florida Bay, C-111 canal	28	125	Oct. 1985 to Aug. 1986	Swift, D., Water quality measurements taken in the marshes and bays below the C-111 Canal in southwestern Dade County, unpublished data, S. Fla. Water Manage. Dist., West Palm Beach, 1988.
49	NE Florida Bay, Florida Keys	8	78	July 1975 to Sept. 1991	Rich, E., Environmental data collected in Florida Bay, unpublished data, Univ. of Miami, Coral Gables, Fla., 1991.
50	West coast estuaries, Whitewater Bay	19	65	April 1986 to Sept. 1989	Bancroft, G. T., S. D. Jewell, and A. M. Strong, Foraging and nesting ecology of herons in the lower Everglades relative to water conditions, *Final Rep. 202-M86-0254-R*, to S. Fla. Water Manage. Dist., 156 pp. and appendix, Natl. Audubon Soc., Tavernier, Fla., 1990.

Table A2. (continued)

Study	Location	Number of Stations	Number of Observations	Period Sampled	Reference
51	nearshore Gulf of Mexico, west coast estuaries, Whitewater Bay	35	140	May 1971 to Feb. 1972	Lindall, W. N., Jr., J. R. Hall, W. A. Fable Jr., and L. A. Collins, Fishes and commercial invertebrates of the nearshore and estuarine zone between Cape Romano and Cape Sable, Florida, South Florida Ecological Study Appendix E, Estuarine-Dependent Marine Fishes, Part II, Sect. II, 59 pp., Gulf Coastal Fish. Cent., St. Petersburg Beach Lab., Natl. Mar. Fish. Serv., St. Petersburg Beach, Fla., 1973.
52	west, central Florida Bay	52	90	June 1988 to Sept. 1990	Durako, M. J., Environmental data collected in association with seagrass die-off studies in Florida Bay, unpublished data, (contract CA5280-9-8002 to Fla. Mar. Res. Inst., Dep. of Nat. Resour., St. Petersburg, Fla.) S. Fla. Res. Cent., Everglades Natl. Park, Homestead, Fla., 1990.
53	west Florida Bay, Florida Keys	191	191	1972	Davies, T. D., Peat formation in Florida Bay and its significance in interpreting the recent vegetation and geological history of the bay area, Ph.D. dissertation, 338 pp., Pa. State Univ., University Park, 1980.
54	NE Florida Bay	119	440	Jan. 1978 to Sept. 1989	Mazzotti, F. J., The ecology of *Crocodylus acutus* in Florida, Ph.D. dissertation, 161 pp., Pa. State Univ., University Park, 1983.
55	Buttonwood Canal Bridge	1	150	June 1964 to June 1965	Beardsley, G. L., Jr., Distribution in the water column of migrating juvenile pink shrimp, *Penaeus duorarum*, Burkenroad in Buttonwood Canal, Everglades National Park, Florida, Ph.D. dissertation, 91 pp., Univ. of Miami, Coral Gables, Fla., 1967.
56	Largo Sound, nearshore Atlantic Ocean	5	250	Nov. 1982 to Dec. 1986	Skinner, R. H., Salinity observations from the water quality monitoring program of John Pennekamp Coral Reef State Park, unpublished data, 1982–1986.
57	nearshore Gulf of Mexico, west-coast estuaries, Whitewater Bay	35	140	May 1971 to Feb. 1972	Collins, L. A., and J. H. Finucane, Ichthyoplankton survey of the estuarine and inshore waters of the Florida Everglades, May 1971 to February 1972, *NOAA Tech. Rep. NMFS 6*, 75 pp., Natl. Oceanic Atmos. Admin., Miami, Fla., 1984.
58	west, central Florida Bay	5	115	June 1989 to June 1990	Sheridan, P. F., Environmental observations associated with seagrass die-off studies conducted in Florida Bay by the National Marine Fisheries Service, unpublished data, Galveston Lab., Galveston, Tex., 1990.
59	Whitewater Bay	8	120	Jan. 1968 to June 1969	Clark, S. H., Factors affecting the distribution of fishes in Whitewater Bay, Everglades National Park, Florida, Ph.D. dissertation, 100 pp., Univ. of Miami, Coral Gables, Fla., 1970.
60	Florida Bay	30	670	Sept. 1993 to Dec. 1995	Colvocoresses, J., Data from the Florida Marine Fisheries-Independent Monitoring Program in Florida Bay, unpublished data, Fla. Mar. Res. Inst., Marathon Lab., Marathon, Fla., 1995.

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